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Procedure and Equipment for Multi-Dimensional Modulation and Demodulation of Binary Signals

[Procede et appareils de modulation et de demodulation multidimensionnelle de signaux binaries]

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Procedure and Equipment for Multi-Dimensional Modulation and Demodulation of Binary Signals

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ABSTRACT

In order to carry out modulation the procedure consists in transcribing 1 each binary signal of the vector one-dimensional space in order to obtain a signal that can be represented in a vector space with N dimensions. Each transcribed signal is represented with respect to a base of the vector space with N dimensions in the form of a series of elementary signals, each formed by one term of a linear combination of the elements of the base. The set of the transcribed signals is classified 3 in this base in families of signals described by one representative, all signals of a single family having the same energy level, and in multiplexing the resulting elementary signals in each family for the purpose of their transmission 5. In order to carry out demodulation, the received transcribed signal is identified in its family by comparing its energy to those of the representatives. An address decoding table allows one to again find each transmitted signal through the representative of the family that has the energy that is closest to that of the

[1] Numbers in the margin indicate pagination in the foreign text.

received signal and by the characteristics of sign and amplitude of each of the elementary received signals.

Application: transmission of information.

The present invention pertains to a procedure and equipment for multi-dimensional modulation and demodulation of binary signals.

Information theory, whose principles were established by the mathematician Shannon, allows one to evaluate the capacity of a transmission channel, that is to say the maximum flow rate of information that can be carried without error over a transmission channel in the presence of noise. This flow rate is called the channel capacity. However, this flow rate turns out to be a theoretical maximum that is impossible to reach in practice. And in addition, information theory does not provide a method for building communication systems that allow one to even roughly approach the estimated theoretical flow rates.

However, this theory is remarkable in that it utilizes the concept of multi-dimensional space, pushed to its limit, that is to say it has an infinite number of dimensions. In place of binary signals with one dimension, as is traditionally done for FSK type modulations, for example FSK being the abbreviation of the British term "frequency shift keying," the signals in question are signals that can be chosen among a number M that is very large of possible signals, each signal being provided with a

number N of dimensions that is very large, that is to say it is comprised of N distinct samples that can independently disturbed by noise.

The use of a large number of dimensions leads one on the theoretical level to consider a spherical model for representation of signals in which the signals M are points located inside a sphere of radius R. In this case the minimal distance that separates two distinct points increases with the number of dimensions in question. One can then express this fact by stating that if one desires to have available M distant points from at least one minimal distance, in a sphere with N dimensions, the radius R of the sphere decreases when the number N of dimensions increases. /2

Consequently, since the radius of the sphere increases with average signal energy, and since the error probability that represents the danger of confusion between two adjacent signals varies in a decreasing manner as a function of the minimal distance d, one can see that it is possible to improve the performance of a link by grouping k elementary signals of one space with n dimensions, by providing for each the possibility of assuming m distinct values, in order to transform them into symbols with $M=m^k$ values in a space with $N=n \bullet k$ dimensions.

However, the entire difficulty consists in choosing an arrangement of M points at compact as possible while ensuring

that the N components of the received signal are easily uncorrelated from the standpoint of noise unless the principle presented earlier is no longer valid: indeed, the fact that it is the distance between distinct signals that determines the performance is narrowly related to the presence of uncorrelated gaussian noise for each of the components. It is also necessary that the width of the signal band remains unchanged and that the complexity of the system remains within reasonable limits.

The aim of the invention is to propose a solution to the problem presented.

For this purpose the invention has as one object a procedure for multi-dimensional modulation and demodulation of binary signals characterized in that it consists, in order to carry out modulation, in transcribing each binary signal of a vector space with one dimension in order to obtain a signal that can be represented in a vector space with N dimensions, each transcribed signal being represented with respect to a base of the vector space with N dimensions in the form of a series of elementary signals each one formed by one term of a linear combination of elements of the base, the set of transcribed signal being classified in this base in families of signals described by one representative, all signals of a single family having the same energy level, and in multiplexing the elementary signals /3

obtained in each family for the purpose of their transmission, the procedure consisting in carrying out demodulation of the received transcribed signal, in permuting its components in order to rank them in the order of absolute decreasing values and in identifying its family by comparing its energy to that of the representatives, in identifying the sign and amplitude of each elementary signal received and in decoding the received signal in the vector space with one dimension by the decoding table addressed by the representative of the family that has energy that is closest to that of the received signal and by the characteristics of sign and amplitude of each of the elementary received signals.

The invention also has as a goal a device for modulation and a device for demodulation for implementation of the aforementioned procedure.

Other characteristics and advantages of the invention will appear subsequently with the help of the description that follows that is given with regard to the attached drawings that show:

- figure 1 is a table that shows one geometric configuration of signals in a space with four dimensions;
- figure 2 is a table that shows a geometric configuration of signals obtained from the preceding table by a base change;
- figure 3 is one mode of implementation of the modulation device according to the invention;

- figure 4 is one mode of implementation of the demodulation device according to the invention.

Multi-dimensional modulation of binary signals is carried out according to the invention by grouping the base symbols, which comprise the total set of information to be transmitted between transmitter/receiver devices, in packets of samples in order to form an alphabet represented by $M=m^N$ signals with N dimensions.

The signal received by the receiving unit is shown by a set of N samples of the form /4

$$s(I) = |s_1(I),\ s_2(I)\ldots s_i(I)\ldots s_N(I)| \qquad (1)$$

with $s_i(I) = A_i(I)+X_i$ (2) for $I = 1\ldots N$

In expression (2) $A_i(I)$ designates the amplitude of the sample $s_i(I)$ and X_i designates the noise that accompanies the sample when it is received by the receiving unit. One can consider subsequently in the description that this noise is gaussian, centered, uncorrelated and has a type G deviation.

In order to carry out the distribution in packets, a transcriber transforms each binary signal representing information to be transmitted and referenced in a vector space with one dimension, into a signal represented by a vector space with N dimensions with respect to a base of this space.

The choice of points of the network of the thus constituted vector space and representative of M possible signals is determined so that the set of M points is represented inside a sphere of the smallest possible radius: one thus obtains a minimal average energy of signals.

In this network the signals are classified by families each one described by a representative, the symbols of a single family having the same energy.

This arrangement allows one, in the execution of the process of demodulation, to identify each signal by comparing its energy to that of all representatives and to carry out as a function of the signs and its components in the vector space with N dimensions and of their amplitude a tabular study of the binary signal that corresponds to it in the vector space with one dimension.

An example of implementation of the procedure according to the invention is described subsequently. In this example the base symbols are grouped in packets of four samples. The treatment is carried on an alphabet of $M=n^4=256$ signals, in a vector space with N=4 dimensions, each signal carrying one octet of information.

In this case each signal is according to a relationship (1) represented by a set of four samples of the form

$$s(I) = |s_1(I), s_2(I), s_3(I), s_4(I)| \quad (3)$$ /5

such that $s_i(I) = A_i(I) + X_i$ for I=1, 2, 3, 4 in reception.

We therefore define for each of the 256 possible signals a set of four amplitudes A_1, A_2, A_3 and A_4 that are called the components of the signal.

The distribution of M signals in the vector space with N dimensions is defined by the points of the space whose coordinates correspond to half integers of the even sum. That is to say, if in the network thus formed $|x_1, x_2, x_3, x_4|$ designates the coordinates of a point that belongs to the network, each of the coordinates x_i verifies one relationship of the form

x_i ½ k_i

where k_i is a whole integer and i= 1, 2, 3, 4.

and the sum $x_1 + x_2 + x_3 + x_4$ is even.

This distribution is the one that allows one in a vector space with 4 dimensions to obtain the most compact arrangement possible for which the M signals are closest to one another. It can be compared, for example,to hexagonal pavement, which, in a space with two dimensions, also gives the most compact distribution.

A table that illustrates one possible geometric configuration of these signals is shown in figure 1. In this table the different representative points of the signals are defined with respect to representatives. The set of points is deduced from representatives by permutations and changes of sign

by assuring that the sum of their coordinates is a multiple of four. This last condition is necessary in order to eliminate exactly half of all possibilities of sign change.

One thus obtains seven groups or families numbered from 1 to 7 with one representative in each group or family. The groups 1 to 7 each include 8 points, the groups 2, 4 and 5 each include 32 points, the group 3 includes 48 points and the group 6 includes 96 points, which in total represents the 256 representative points of the 256 signals in the network. Since the coordinates of the representatives of the groups 1 to 7 have respectively for values (1,1,1,1); (-3,1,1,1); (3,3,1,1); (5,1,1,1); (-3,3,3,1); (-5,3,1,1); (3,3,3,3) the energies, $E^2=x_1^2 + x_3^2 + x_3^2 + x_4^2$ carried by each of the points of the groups 1 to 7 have respectively for values 4, 12, 20, 28, 28, 36 and 36. /6

The coordinates of the points of group 1 form in the vector space with four dimensions vectors that are orthogonal or opposite one another in a number of 8.

The first four of them correspond indeed to the four known Walsh sequences of dimension equal to 4, which means:

$W_1 = |+1,+1,+1,+1|$

$W_2 = |+1,-1,+1,-1|$

$W_3 = |+1,+1,-1,-1|$

$W_4 = |+1,-1,-1,+1|$

These four orthogonal sequences form a base in the vector space with 4 dimensions as defined previously.

The coordinates of each of the representative points of the signals of the space with 4 dimensions can then be expressed as a function of the components of each of the vectors of this base according to the relationship

$$|x_1, x_2, x_3, x_4| = 4/j=1\ y_i W_i \quad (9)$$

In applying this relationship to the set of points, the table of figure 1 is simplified in the way shown by the table of figure 2 which is equivalent to that of figure 1, the only difference however being that all the permutations and all the changes of sign of coordinates of each of the representatives are authorized.

There will correspond to the seven initial groups, in the table of figure 2, six incoming groups g numbered from 1 to 6, whose representatives $|y_1(g),\ y_2(g),\ y_3(g),\ y_4(g)|$ have respectively for values, 1000 for group 1, 1110 for group 2, 2100 for group 3, 2111 for group 4, 2210 for group 5 and 3000 for group 6. There exists under these conditions 8 points for the incoming group 1, 32 points for the incoming group 2, 48 points for the incoming group 3, 64 points for the incoming group 4, 96 points for the incoming group 5 and 8 points for the incoming group 6, which forms a total representation of 256 points.

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Under these conditions each signal shown has an energy $E^2(g)$ = $y^2{}_1(g) + y^2{}_2(g) + y^2{}_{3(g)} + y^2{}_4(g)$ equal to 1 for the eight points of group 1 and equal to 3 for the 32 points of group 2. The energies of the signals shown here by each point of the groups 3, 4, 5 and 6 have respectively for values 5, 7, 9 and 9.

In addition to the fact that all possible values of the permutations $y_1(g)$ $y_2(g)$ $y_3(g)$ and $y_4(g)$ are authorized, one can determine that their number is exactly equal to a power of 2 ($M=256 = 2^8$) which precludes one from rejecting some of them.

Indeed, the fact of rejection of some signals would have the troublesome consequence of presenting a problem of choice for transmission, that is which one must keep in order to have a better signal-to-noise ratio, and at reception a problem of decision for demodulating these signals.

The advantage of the coding shown by the table of figure 2, is that is corresponds to a set of representative points of the signal, that one can consider as optimal in the sense that it is the most compact possible and that it is complete, no element having to be added or retracted.

The demodulation of the signal shown by the table of figure 2 is carried out by taking into account noise which naturally affects in a transmission each received signal. Under these conditions, for each signal Y that is transmitted and defined by

the components y_i where i = 1, 2, 3, 4 corresponds at reception to a signal R defined by the components r_i such that:

$r_i = y_i + X_i$ (10)

X_i representing the noise for the first component that one considers in the series as gaussian noise, centered and uncorrelated between components.

Therefore, the probability of finding without error good information I is such that it makes maximal the conditional probability of obtaining good information I from the signal R that is received. /8

Considering the hypotheses made regarding noise this probability can be expressed according to the normal gaussian law

$P=4/i=1\ (G \cdot \sqrt{2}\,\P)^{-1} \cdot \exp(-(r_i-y_i(I))^2/2\ G\ ^2)$ (11)

G being the type deviation.

In making the logarithm of this probability maximum, one can determine that it suffices that I makes minimum the distance between the point representing the first signal and the one corresponding to the received signal.

This distance is defined by the relationship

$D^2(I) = 4/i=1\ (r_i-y_i(I))^2$ (12)

Since the energy of all signals of a group is constant and equal to

$E^2(I) = 4/i=1\ y_i^2(I)$ (13)

it reduces in the same way to making the relationship maximum

$(I) = 2\ 4/i=1\ r_i \cdot y_i(I) = E^2(I)$ (14)

In order to carry out this operation on each of the combinations (r_1, r_2, r_3, r_4) with each characterizing a received signal, the elementary signals r_1 are ranked in order of decreasing values, and are written in a memory. The corresponding permutation as well as the changes of sign that result from it from each signal are memorized. The procedure consists next in calculation for each group (g) represented by its representative the quantity:

$$\Delta(g) = 2^{\Delta}{}_{I=1} \left|r_{ni}\right| \cdot y_i(g) - E^2(y) \qquad (15)$$

with $1 \leq g \leq 6$

The most likely group is then the group that makes maximum the quantity $\Delta(g)$, the member of the group that is most likely transmitted being the one that, by using the permutation (n_1, n_2, n_3, n_4), is transformed into the representative of the said group and whose coordinates have the same signs as the received elementary signals r_i.

As an example, assuming at reception a signal has respectively for its values

$r_1 = 0.1$ $r_2 = -0.9$ $r_3 = 0.3$ $r_4 = -0.15$

One will obtain successively, by applying the aforementioned procedure: /9

- the memorized signs

+1 -1 +1 -1

- the order of the permutation

  2 3 4 1

- the classification of the absolute values

  0.9 0.2 0.15 0.1

- and for each of the groups of the table of figure 2 the following values of Δg:

group 1	$\Delta(1)$	=	0.9 - 1 = 0.1
group 2	$\Delta(2)$	=	1.25-3 = -1.75
group 3	$\Delta(3)$	=	2 - 5 = - 3
groups 4 and 5	$\Delta(4,5)$	=	2.25 - 7 = - 4.75
group 6	$\Delta(6)$	=	2.35 - 9 = - 6.65
group 7	$\Delta(7)$	=	2.7 - 9 = - 6.3

It appears, in this example, that group 1 yields the best result. Its representative is the group defined by the combination

$g_1 = 1000$

By applying to this representative, the order 2, 3, 4, 1 of the permutations and by assigning to it the corresponding stored signs, one will obtain the transmitted signal $Y=|0, -1, 0, 0|$.

It then suffices to apply this combination to a correspondence table in order to obtain the binary value of the transmitted signal that corresponds in the space with one dimension.

One example of implementation of the procedure according to the invention is shown in figures 3 and 4 which show respectively, a device that allows a modulation of binary signals and a demodulation device, and some signals modulated by the device in figure 3.

The device shown in figure 3 includes a transcriber 1, a permutation unit 2, a memory of representatives 3, a matrix operator 4 and a modulation device 5.

The transcriber 1, comprised possibly of a programmable read-only memory, carries out the transcribing shown by the table of figure 2. It supplies at three outputs designated respectively by 1a, 1b and 1c some elementary signals that are representative of the groups of 1 to 7 of the table of figure 1, the order of the permutation of each member of a group and the signs to be assigned to each elementary signal of each member of a group as a function of the binary signals (I) coded with 8 bits, representing the information to be transmitted.

The signals of the group furnished by the output 1a are applied to the address inputs of the memory of representatives 3 that contains the table of amplitudes (y_1, y_2, y_3, y_4) of the elementary signals of each group of the table of figure 2.

These elementary signals are applied to the inputs of the permutation unit 2 and are permuted as a function of the order furnished by output 1b of the transcriber 1. The permuted

signals are applied to the first operand inputs of multiplier circuits 6a, 6b, 6c and 6d whose two operand inputs receive respectively the sign bits furnished by the output 1c of the decoder 1. The results of the multiplications are then applied to the inputs of the matrix operator 4, comprised for example in the known manner, by a set of additional multiplier circuits to carry out the matrix products of components y_1 to y_4 with the coefficients U_{ij} of a matrix $-|U|$ of signals applied to the matrix operator 4.

The choice of coefficients u_{ij} of the matrix $|U|$ depends on the type of modulation employed in the modulation device 5 and on the constraints imposed on transmission, especially those on width of the transmission spectrum. In the hypothesis where, in the chosen transmission mode, each signal sample is decorrelated into noise and has the same variance, the coefficients U_{ij} could constitute an orthonormal base in the vector space with four dimensions of table 2. In the opposite case, the coefficients U_{ij} will be those of a matrix of non-orthogonal vectors of the space. In either case, the matrix operator 4 furnishes for each modulated signal a signal formed by components $|e_1, e_2, e_3, e_4|$ that results from the matrix product <u>/11</u>

$$|U| \cdot (y_1, y_2, y_3, y_4)$$

The components e_1, e_2, e_3 and e_4 are applied to the inputs of the modulation device 5 which ensures their multiplexing in

the known manner, for example by frequency, by phase and/or by amplitude, before transmitting them to a demodulation device of which one example of implementation is shown in figure 4.

The demodulation device shown in figure 4 includes a demodulation device 7, a matrix operator 8, a device for calculating the sign and absolute value 9, sequencing software 10, calculation unit 11 of $\Delta(g)$, a first storage unit of representatives 12, an address counter 13, a group calculation software 14, a second storage of representatives 15, a permutation unit 16, a sign assignment software 17, and transcription storage 18.

The signals received by the demodulator unit 7 are the replica in frequency, in phase or in amplitude of each of the components e_1 to e_4 that is transmitted. Once demultiplexed these signals are applied to the input of the matrix operator 8 in order to be decorrelated into noise. This operator is comprised in the known manner, by a set of multiplier and adder circuits, which produce the product of components of the signal demodulated by the demodulator 7 by the inverse matrix $|U|^{-1}$ of the matrix $|U|$.

In this way one obtains at the output of the operator 7 these signals r_1, r_2, r_3 and r_4 which are noise decorrelated. These signals are applied to the inputs of the calculation device of signs and absolute value 9. The latter furnishes, on the one

hand, the sign indicator signals (s_1, s_2, s_3 and s_4) that accompany each ingredient (r_1, r_2, r_3 and r_4) and on the other hand the absolute corresponding values $|r_1|$, $|r_2|$, $|r_3|$ and $|r_4|$. These absolute values are ranked in decreasing order by the sequencing software 9 that supplies on the one hand at the first outputs the order of the permutations n_1, n_2, n_3 and n_4 and on the other hand, for the second outputs the absolute value is ranked in the calculation unit 11. /12

The calculation unit 11 calculates the value $\Delta(g)$ given by the relationship (15). To do this it is connected to a memory 12 possibly formed by a programmable read-only memory that contains the set of 256 signals $|y_1 \ldots y_4|$ of the alphabet and for each of them the value $E^2(g)$ of their energy. The 256 signals of the memory 11 are addressed by an address counter 13. The set of the results $\Delta(g)$ obtained at the output of the calculation unit 11 is transmitted to the calculation software 14 that determines the group for which the value of $\Delta(g)$ is at a maximum. This last value is applied to the addressing inputs of the memory 15, comprised possibly of a programmable read-only memory or any equivalent device in which a table of representatives of the groups is also inscribed. The samples of the representative corresponding to the group selected by the software 14 are applied to the permutation unit 16. The latter are permuted in the order indicated by the signals n_1, n_2, n_3 and n_4 supplied by

the sequencing software 10. The resulting permutation is applied to the sign assignment software 17 that attributes to each element of the permutation the corresponding sign supplied by the calculation device 9.

Each resulting signal supplied by the sign assignment software 17 is applied to the address inputs of the transcription memory 18 that comprises the corresponding binary transmitted signal encoded in 8 bits.

The procedure and the devices of modulation and demodulation that have just been described in a space structure with four dimensions allow one to obtain performance levels superior to those that can be obtained with a space structure with only one dimension.

In the example of modulation and demodulation that has just been described the number of bits carried per symbol is $\log_2 M = 8$, the minimal distance (dmin) between symbols represented by their component y_i) is equal to $\sqrt{2}$ (d_{min} = the distance between $|1000|$ and $|0100|$) and the average energy equals

$$E^2 = 256/I=1 \ (4/i=1 \ (y^2{}_j(I))/256 = 6.75 \qquad \underline{/13}$$

The geometric measurement of the performance is given by the ratio

$$\gamma = E^2/(d^2{}_{min} \times \log M) \text{ where } \gamma = 0.42$$

Compared to a known type modulation in a space with only dimension of the type 4FSK for example, where each symbol carries

only $\log_2 m$ = 2 bits of information and where the useful information can assume only 4 values represented by the weights -3, -1, +1 and +3 the minimal distance between the symbol being equal to 2A and the average energy E^2 being equal to $5A^2$, and where the resulting ratio is equal to 0.625, it appears clearly that the proposed modulation will consequently improve the performance levels by 0.675 times.

Naturally, since the invention is not limited to the example of implementation that has just been described in this space with 4 dimensions, one can image that one could improve even more these performance levels by extending the described procedures in multi-dimensional spaces of orders greater than 4.

One could also imagine that other modes of implementation of the invention that are different from the one that was just described are also possible by changing in particular the structure of the circuits used. As an example one could envisage carrying out the different calculations described previously by using a micro-programmed architecture that implements one or several microprocessors. /14

CLAIMS

1. Procedure of multi-dimensional modulation and demodulation of binary signals characterized in that it consists, in order to carry out the modulation, in transcribing (1) each binary signal of the vector space

with one dimension in order to obtain a signal that can be represented in a vector space with N dimensions, each transcribed signal being represented with respect to a base of the vector space with N dimensions in the form of a series of elementary signals, each one formed by one term of a linear combination of elements of the base, the total set of transcribed signals being classified (3) in this space in families of signals described by one representative, all signals of the same family having the same level of energy, and in multiplexing the resulting elementary signals obtained in each family for the purpose of their transmission.

2. Procedure according to claim 1 characterized in that it consists, in order to carry out the demodulation of the received transcribed signal, in identifying (11, 12, 13, 14) its family by comparing its energy to those of the representatives, in identifying (9) the sign and amplitude of each elementary signal received and in decoding (18) the received signal in the vector space with one dimension by an address decoding table through the representative of the family that has the energy closest to that of the received signal and by the characteristics of sign and amplitude permutation of each of the received elementary signals.

3. Procedure according to any of the claims 1 and 2 characterized in that the vector space is a space with four dimensions formed of 256 signals, each signal being represented by a set of four samples.

4. Procedure according to claim 3 characterized in that the distribution of the 256 signals is defined by the points of the space with four dimensions whose coordinates correspond to even sum half/whole integers.

5. Procedure according to claim 4 characterized in that the distribution of the 256 signals is carried out in 7 groups that have a predetermined energy. /15

6. Procedure according to claim 5 characterized in that the coordinates of the points of one of the groups form in the vector space of vectors that are orthogonal or opposite one another, four of them that form a Walsh sequence.

7. Procedure according to claim 6 characterized in that the set of Walsh sequences is used as the base for the set of 256 signals of the space with four dimensions.

8. Procedure according to any of the claims 1 to 7 characterized in that each signal sample is decorrelated into noise (4, 8).

9. Modulation device for the implementation of the procedure according to any of the claims 1 to 8,

characterized in that it includes a transcriber 1 for transcribing each binary signal to be transmitted in the form of an identification signal of the group to which the signal belongs, with an order of permutation of its components with respect to that of the representative, and of a series of signs to be assigned to each component, a memory of representatives (3) addressed by the identification signal of the group, a permutation unit (2) to permute the components of the components of the representative identified in the memory of the representatives as a function of the order of permutation supplied by the transcription unit (1), a set of multipliers circuits (6a, 6b, 6c, 6d) for applying to each signal component furnished by their permutation unit (2) a corresponding signal furnished by the transcription unit (1), a modulation device (5) for transmitting each resulting signal furnished by a set of multiplier circuits with destination of a demodulation device, the modulation device (5) being connected to the set of multiplier circuits (6a, 6b, 6c, 6d) through a matrix operator (4) in order to noise decorrelate the signals transmitted by the modulator (5).

10. Demodulation device for implementation of the aforementioned procedure and intended to be coupled to the modulation device according to claim 9, characterized in that it includes a demodulation unit (7), a matrix operator (8), for noise decorrelating the components of each signals furnished by the demodulation unit (7), a calculation device of the signs and absolute values (9) of each signal component that is demodulated, a sequencing software (10) of the absolute values of the signal components demodulated in decreasing order, a calculation unit (11) coupled to a calculation software package of the group to which the received signal belongs in order to calculate from energies of the set of signals the most favorable group corresponding to the energy of the received signal, a memory unit of representatives (15) in order to designate a corresponding representative for the most favored found group, a permutation unit (16) controlled by the sequencing software (10) in order to re-establish the order of the received signal from the resulting representative of the memory of the representatives (15), a sign assigning software (17) for assigning one sign to each component of the signal obtained at the output from the permutation unit (17)

as a function of the signs furnished by the sign calculation software (9), and a transcription memory unit (18) for restoring each signal transmitted as a function of the signal supplied by the sign assignment software (17).

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FIG_1

GROUPE	REPRESENTANTS x_1	x_2	x_3	x_4	$x_1^2+x_2^2+x_3^2+x_4^2$	NOMBRE DE POINTS
1	1	1	1	1	4	8
2	-3	1	1	1	12	32
3	3	3	1	1	20	48
4	5	1	1	1	28	32
5	-3	3	3	1	28	32
6	-5	3	1	1	36	96
7	3	3	3	3	36	8
					TOTAL	256

FIG_2

GROUPE DE DEPART	GROUPE D'ARRIVEE g	REPRESENTANTS $y_1(g)$	$y_2(g)$	$y_3(g)$	$y_4(g)$	$E(g)=y_1^2+y_2^2+y_3^2+y_4^2$	NOMBRE DE POINTS
1	1	1	0	0	0	1	8
2	2	1	1	1	0	3	32
3	3	2	1	0	0	5	48
4, 5	4	2	1	1	1	7	64
6	5	2	2	1	0	9	96
7	6	3	0	0	0	9	8
						TOTAL	256

Fig. 1.

Key: 1-group; 2-representatives; 3-number of points; 4-total

Fig. 2.

Key: 1-initial group; 2-incoming group; 3-representatives; 4-number of points; 5-total.

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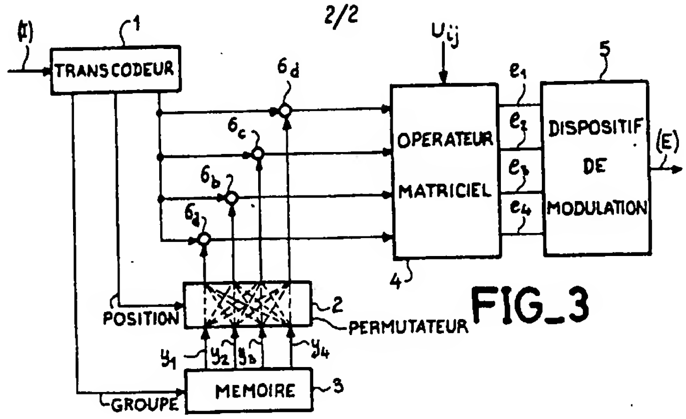

FIG_3

FIG_4

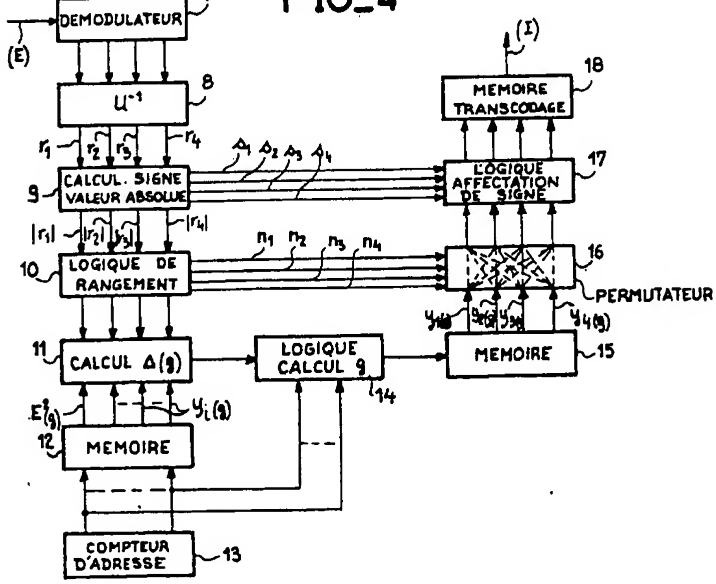

Fig. 3.

Key: 1-transcription unit; 2-position; 3-group; 4-memory, storage; 5-permutation unit; 6-matrix operator; 7-modulation device.

Fig. 4.

Key: 1-demodulator; 2-absolute value and sign calculation; 3-sequencing software; 4-Δ calculation unit; 5-memroy, storage; 6-address counter; 7-calculation software; 8-transcription memory; 9-sign assignment software; 10-permutation unit; 11-memory, storage.